Appendix J – Assessment of Research Regarding EMF and Health and Environmental Effects

SCHULTZ - HANFORD AREA TRANSMISSION-LINE PROJECT

APPENDIX J:

ASSESSMENT OF RESEARCH REGARDING EMF AND HEALTH AND ENVIRONMENTAL EFFECTS

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1.0 Introduction

Over the last 20 years, research has been conducted in the United States and around the world to examine whether exposures to electric and magnetic fields (EMF) at 50/60 hertz (Hz) from electric power lines are a cause of cancer, or adversely affect human health. The research included epidemiology studies that suggested a link with childhood for some types of exposures, as well as other epidemiology studies that did not; it also included lifetime animal studies, which showed no evidence of adverse health effects. Comprehensive reviews of the research conducted by governmental scientific agencies in the U.S. and in the United Kingdom (UK) had examined the research, and did not find a basis for imposing additional restrictions (NIEHS, 1999; IEE, 2000).

The Bonneville Power Authority (BPA) requested that Exponent review the research on EMF and health and focus on exposures that might occur from the Schultz – Hanford Area Project. In December 2000, Exponent prepared a report to the BPA that summarized our assessment of the research regarding EMF and health (to be published as an appendix to the Kangley-Echo Lake Transmission Project environmental impact statement, summer 2001). This report was prepared after the National Institute of Environmental Health Sciences (NIEHS) had just completed the Congressionally funded research program known as RAPID (Research and Public Information Dissemination Program), and after publication of the NIEHS Working Group Report (NIEHS, 1998). Consequently, our report to the BPA presented the conclusions of these scientific panels, and reviewed the major research studies published after the NIEHS report was completed.

This update concentrates on recent major research studies to explain how they contribute to the assessment of effects of EMF on health. The focus is on both epidemiologic and laboratory research, because these research approaches provide different and complementary information for determining whether an environmental exposure can affect human health.

2.0 Health

2.1 The NIEHS Report and Research Program

In 1998, the NIEHS completed a comprehensive review of the scientific research on health effects of EMF. The NIEHS had been managing a research program that Congress funded in 1996, in response to questions regarding exposure to EMF from power sources. The program was known as the RAPID Program (Research and Public Information Dissemination Program). The NIEHS convened a panel of scientists (the "Working Group") to review and evaluate the RAPID Program research and other research. Their report, *Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields,* was completed in July 1998 (NIEHS, 1998).

The director of the NIEHS prepared a health risk assessment of EMF and submitted his report to Congress in June 1999 (NIEHS, 1999). Experts at NIEHS, who had considered the previous Working

Group report, reports from four technical workshops, and research that became available after June 1998, concluded as follows:

> The scientific evidence suggesting that ELF-EMF [extremely low frequency-electric and magnetic field] exposures pose any health risk is weak. The strongest evidence for health effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed adults. . . . In contrast, the mechanistic studies and animal toxicology literature fail to demonstrate any consistent pattern . . . . No indication of increased leukemias in experimental animals has been observed. . . . The lack of consistent, positive findings in animal or mechanistic studies weakens the belief that this association is actually due to ELF-EMF, but it cannot completely discount the epidemiology findings. . . . The NIEHS does not believe that other cancers or other non-cancer health outcomes provide sufficient evidence of a risk to currently warrant concern (pp. 9-10).

Although the results of the RAPID research are described in some detail in the 1998 report, many of the studies had not been published in the peer-reviewed literature. Recognizing the need to have these results reviewed and considered for publication, the NIEHS arranged for a special edition of the journal *Radiation Research* (Radiation Research, 153(5), 2000) to be devoted to this topic.[1]

2.2 Update of Research Related to Cancer

The California Department of Health Services conducted a workshop in 1999 to discuss epidemiologic research on EMF and health. The reports presented at this workshop recently became available (published in January 2001) as a supplement to the journal, *Bioelectromagnetics*. Many of the papers were technical discussions of methodology issues in epidemiologic studies of EMF, including discussions of how better to understand the conflicting results reported in previous studies (Neutra and Del Pizzo, 2001). For example, one study evaluates the extent to which systematic errors (known in epidemiology as selection bias or information bias) occurred in EMF studies and if so, whether they can be measured (Wartenberg, 2001a). Other researchers discuss epidemiologic approaches to study how possible confounding factors, such as the age and type of home and traffic density, might affect the interpretation of studies of EMF and childhood cancer (Langholz, 2001; Reynolds et al., 2001).

For this update, we review papers from this workshop that provide new information or statistical analyses. Several of the studies are "meta-analyses," an approach that incorporates statistical methods to analyze differences and aggregate the results of smaller studies. The section below includes a review of meta-analyses of the studies of childhood leukemia through 1999, and a meta-analysis of studies of breast cancer in adults (Erren et al., 2001).

2.2.1 Epidemiology Studies of Children

The question of power lines and childhood cancer has been based on the assumption that the relevant exposure associated with power lines is the magnetic field, rather than the electric field. This assumption rests on the fact that electric fields are shielded from the interior of homes (where people spend the vast majority of their time) by walls and vegetation, while magnetic fields are not. The magnetic field in the

[1] See, for instance, the articles cited in the **List of References** under Balcer- Kubiczek, Boorman, Loberg, and Ryan.

vicinity of a power line results from the flow of current; higher currents result in higher levels of magnetic fields.

Epidemiologic studies report results in the form of statistical associations. The term "statistical association" is used to describe the tendency of two things to be linked or to vary in the same way, such as level of exposure and occurrence of disease. However, statistical associations are not automatically an indication of cause and effect, because the interpretation of numerical information depends on the context, including (for example) the nature of what is being studied, the source of the data, how the data were collected, and the size of the study. The larger studies and more powerful studies of EMF have not reported convincing statistical associations between power lines and childhood leukemia (e.g., Linet et al., 1997; McBride et al., 1999; UKCCS, 1999). Despite the larger sample size, these studies usually had a limited number of cases exposed over 2 or 3 milligauss (mG).

The following discussion briefly describes major studies.

- A study from British Columbia, Canada, included 462 children who had been diagnosed with leukemia and an equal number of children without leukemia for comparison (McBride et al., 1999). Magnetic-field exposure was assessed for each of the children in several ways: personal monitors were worn in a backpack for 48 hours, a monitor took measurements in the bedroom for 24 hours, the wiring outside the house was rated by potential exposure level, and measurements were taken around the outside perimeter of the homes. Regardless of the method used to estimate magnetic-field exposure, the magnetic-field exposure of children who had leukemia was not greater than that of the children in the comparison group.

- A study conducted in Ontario, Canada reported on the magnetic-field exposure of a smaller group of children (Green et al., 1999a). No increased risk estimates were found with the average magnetic fields in the bedroom or the interior, or with any of the three methods of estimating exposure from wire configuration codes. (Wire codes are a method of estimating relative exposure intensity based on the configuration of the power lines.) A still smaller group of 88 children with leukemia and their controls wore personal monitors to measure magnetic fields (Green et al., 1999b). Associations with magnetic fields were reported in some of the analyses, but most of the risk estimates had a broad margin of error and major methodological problems in the study preclude any clear interpretation of the findings.

- The United Kingdom Childhood Cancer Study, the largest study to date, included a total of 1073 childhood leukemia cases (UKCCS, 1999). Exposure was assessed by spot measurements in the home (bedroom and family room) and school, and summarized by averaging these over time. No evidence was found to support the idea of an increased risk of leukemia from exposures to magnetic fields from power sources inside or outside of the home.

- The UKCCS investigators had obtained magnetic-field measurements on only a portion of the cases in their study (UKCCS, 1999). To obtain additional information, they used a method to assess exposure to magnetic fields without entering homes; they were thus able to analyze 50% more subjects (UKCCS, 2000). For all these children, they measured distances to power lines and substations. This information was used to calculate the magnetic field from these external field sources, based on power-line characteristics related to production of magnetic fields. The results of the second UKCCS study showed no evidence for an association with leukemia for magnetic fields calculated to be between 1 mG and 2 mG, 2 mG and 4 mG, or 4 mG or greater at the residence, in contrast to the weak association reported for measured fields of 4 mG or greater in the first report (UKCCS, 1999).

Recently, researchers reanalyzed the data from previous epidemiology studies of magnetic fields and childhood leukemia (Ahlbom et al., 2000; Greenland et al., 2000). The researchers pooled the data on individuals from each of the studies, creating a study with a larger number of subjects and therefore greater statistical power than any single study. A pooled analysis is preferable to other types of meta-analyses in which the results from several studies are combined from grouped data obtained from the published studies. These analyses focused on studies that assessed exposure to magnetic fields using 24-hour measurements or calculations based on the characteristics of the power lines and current load. Both Greenland et al. and Ahlbom et al. used exposure categories of <0.1 microtesla (μT) (<1 mG) as a reference category. The statistical results of these analyses can be summarized as follows:

- The pooled analyses provided no indication that wire codes are more strongly associated with leukemia than measured fields.

- Pooling these data corroborates an absence of an association between childhood leukemia and magnetic fields for exposures below 0.3 μT (3 mG).

- Pooling these data results in a statistical association with leukemia for exposures greater than 0.3 or 0.4 μT (3-4 mG).

The authors are appropriately cautious in the interpretation of their analyses, and they clearly identify the limitations in their evaluation of the original studies. Magnetic fields above 0.3 μT in residences are estimated to be rather rare, about 3% in the U.S. (Zaffanella, 1993). Limitations include sparse data (few cases) to adequately characterize a relationship between magnetic fields and leukemia, uncertainties related to pooling different magnetic-field measures without evidence that all of the measures are comparable, and the incomplete and limited data on important confounders (other risk factors for disease that may distort the analysis) such as housing type and traffic density.

A meta-analysis of the data from epidemiologic studies of childhood leukemia studies was presented at the California Workshop and recently published (Wartenberg, 2001b). This meta-analysis did not have the advantage of obtaining and pooling the data on all of the individuals in the studies, unlike those published before it (Ahlbom et al., 2000; Greenland et al., 2000). Rather than individual data, Wartenberg (2001b) used an approach that extracted the published results, reported as grouped data from several published studies. He used 19 studies overall, after excluding 7 studies that had insufficient data on individuals or deficiencies in the exposure assessment data. He reported a weak association for a) "proximity to electrical facilities" based on wire codes or distance, and b) magnetic-field level over 2 mG, based on either calculations from wiring and loading characteristics (if available) or on spot magnetic-field measurements. The results show more cases than controls exposed to measured or calculated fields above 2 mG. The author concludes that the analysis supports an association, although the size of the effect is small to moderate, but also notes "limitations due to design, confounding, and other biases may suggest alternative interpretations" (Wartenberg, 2001b:S-100).

The results of this meta-analysis are not directly comparable to previous ones regarding fields of 3 or 4 mG because the analysis was not based on individual data. The comparison of grouped data used different cut points for the analysis and different criteria for the comparison group. None of these three analyses (Ahlbom et al., 2000; Greenland et al., 2000; Wartenberg, 2001b) includes the results of the UK analysis of over 3000 cases based on calculated fields, which found no association between EMF and childhood cancer, regardless of the exposure level.

2.2.2 Epidemiology Studies of Adults

Studies of adults with certain types of cancer, such as brain cancer, breast cancer, or leukemia, have reported associations with exposure to magnetic fields at residences, but results have not been consistent across studies. Contradictory results among studies argue against a conclusion that the association reflects a cause-and-effect relationship. Studies that include more people, obtain more detailed and individual exposure assessments, or include people who have higher exposures are weighed more heavily by scientists in their assessments of risk.

A study of 492 adult cases of brain cancer in California included measurements of magnetic fields taken in the home and at the front door, and considered the types of power-line wiring (Wrensch et al., 1999). The authors report no evidence of increased risk with higher exposures, no association with type of power line, and no link with levels measured at the front door.

A number of recent studies of breast cancer had focused on electric blankets as a source of high exposure. Electric blankets are assumed to be one of the strongest sources of EMF exposure in the home. Three studies of electric blanket use found no evidence that long-term use increased the risk of breast cancer. Women who developed breast cancer reported no difference in total use of electric blankets, use in recent years, or use many years in the past:

- Gammon et al. (1998) reported that, even for those who kept the blanket on most of the time, no increase in risk was found for those who had longer duration of use (measured in months).

- A study of 608 breast cancer cases also found no evidence of increased use of electric blankets or other home appliances in cases compared to controls, and no indication of increasing risk with a longer time of use (Zheng et al., 2000).

- In a cohort of over 120,000 female nurses, data were obtained on known risk factors for breast cancer as well as electric blanket use (Laden et al., 2000). For a large subset of this group, the questions about exposure were asked before the disease occurred, a step taken to eliminate bias in recalling exposure.

Erren (2001) reported the results of a meta-analysis of the studies of breast cancer, in which the results of 24 different studies in women were statistically aggregated. When the results of all 24 studies were pooled, including studies of workplace exposures, the estimate indicated an association between EMF and a small excess breast cancer risk. The pooled results for exposure to EMF in the vicinity of electrical facilities did not show an association with breast cancer, nor did the results for exposure to EMF from appliance use. However, the meta-analysis also showed a lack of consistency among the results of the individual studies, a broad variation in the designs, and a wide range of methods used to assess exposure. No adjustments were made to the data to give increased weight to studies based on more comprehensive exposure assessments. The author also noted that the weak statistical association might be an artifact rather than an indication of cause-and-effect (Erren, 2001).

2.2.3 Laboratory Studies of EMF

Laboratory studies complement epidemiologic studies of people because the heredity, diet, and other health-related exposures of animals can be better controlled or eliminated. The assessment of EMF and health, as for any other exposure, includes chronic, long-term studies in animals (*in vivo* studies) and studies of changes in genes or other cellular processes observed in isolated cells and tissues in the laboratory (*in vitro*).

Although the results of the RAPID Program are described in some detail in the NIEHS reports (NIEHS, 1998), many of the studies had not been published in the peer-reviewed literature. The RAPID research program included studies of four biological effects, each of which had been observed in only one laboratory. These effects are as follows: effects on gene expression, increased intracellular calcium in a human cell line, proliferation of cell colonies on agar, and increased activity of the enzyme ornithine decarboylase (ODC). Some scientists have suggested that these biological responses are signs of possible adverse health effects of EMF. It is standard scientific procedure to attempt to replicate results in other laboratories, because artifacts and investigator error can occur in scientific investigations. Replications, often using more experiments or more rigorous protocols, help to ensure objectivity and validity. Attempts at replication can substantiate and strengthen an observation, or they may discover the underlying reason for the observed response.

Studies in the RAPID program reported no consistent biological effects of EMF exposure on gene expression, intracellular calcium concentration, growth of cell colonies on agar, or ODC activity (Boorman et al., 2000b). For example, Loberg et al. (2000) and Balcer-Kubiczek et al. (2000) studied the expression of hundreds of cancer-related genes in human mammary or leukemia cell lines. They found no increase in gene expression with increased intensity of magnetic fields. To test the experimental procedure, they used X-rays and treatments known to affect the genes. These are known as positive controls and, as expected, caused gene expression in exposed cells.

Scientists have concluded that the combined animal bioassay results provide no evidence that magnetic fields cause, enhance, or promote the development of leukemia and lymphoma, or mammary cancer (e.g., Boorman et al., 1999; McCormick et al., 1999; Boorman et al., 2000 a,b).

2.2.4 Summary Regarding Cancer

The latest epidemiologic studies of childhood cancer, considered in the context of the other data, provide no persuasive and consistent evidence that leukemia in children is causally associated with magnetic fields measured at the home, calculated based on distance and current loading, or with wire codes. Recent meta-analyses reported no association between childhood cancer and magnetic fields below 2 or 3 mG. Although some association was reported for fields above this level, fields at most residences are likely to be below 3 or 4 mG. The authors of each of these analyses list several biases and problems that render the data inconclusive, and prevent resolution of the inconsistencies in the epidemiologic data. For this reason, laboratory studies can provide important complementary information. Large, well-conducted animal studies provide no convincing evidence that exposure increases the risk of cancer. Animal studies, and studies of initiation and promotion, provide no basis to conclude that EMF increases leukemia, lymphoma, breast, brain or any other type of cancer.

2.3 Research Related to Reproduction

Previous epidemiologic studies reported no association with birth weight or fetal growth retardation after use of sources of relatively strong magnetic fields, such as electric blankets, or sources of typically weaker magnetic fields such as power lines (Bracken et al., 1995; Belanger et al., 1998).

A recent epidemiology study examined miscarriages[2] in relation to exposures to magnetic fields from electric bed heating (electric blankets, heated waterbeds and mattress pads), which result in higher exposures than residential fields in general (Lee et al., 2000). The researchers assessed exposure prior to

[2] The medical term for miscarriage is spontaneous abortion.

the birth (a prospective study) and included information to control for potential confounding factors (other exposures and conditions that affect the risk of miscarriage). This study had a large number of cases and high participation rates. Miscarriage rates were lower among users of electric bed heating.

Studies of laboratory animals exposed to pure 60-Hz fields have shown no increase in birth defects, no multigenerational effects, and no changes that would indicate an increase in miscarriage or loss of fertility (e.g., Ryan et al., 1999; Ryan et al., 2000). Exposed and unexposed litters were no different in the amount of fetal loss and the number and type of birth defects, indicating no reproductive effect of EMF.

In summary, the recent evidence from epidemiology and laboratory studies provides no indication that exposure to power-frequency EMF has an adverse effect on reproduction, pregnancy, or growth and development of the embryo. The results of these recent studies are consistent with the conclusions of the NIEHS.

2.4 Recent Reviews by Scientific Advisory Groups

Reviews of the scientific research regarding EMF and health by the Health Council of the Netherlands were published in 2000 and updated in May 2001. The Institute of Electrical Engineers of the UK published a review in 2000. The National Radiological Protection Board of Great Britain (NRPB) Advisory Group on Non-Ionising Radiation published the most recent review in 2001. This review includes research published in 2000, and includes the most comprehensive discussion of the individual research studies.

2.4.1 National Radiological Protection Board of Great Britain (NRPB) Advisory Group on Non-Ionising Radiation

The conclusions from the report prepared by the NRPB's Advisory Group on Non-Ionising Radiation (AGNIR) on extremely low frequency (ELF) EMF and the risk of cancer are consistent with previous reviews. The eight members from universities, medical schools, and cancer research institutes reviewed the reports of experimental and epidemiological studies, including reports in the literature in 2000. Their general conclusions are as follows:

> Laboratory experiments have provided no good evidence that extremely low frequency electromagnetic fields are capable of producing cancer, nor do human epidemiological studies suggest that they cause cancer in general. There is, however, some epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukaemia in children. In practice, such levels of exposure are seldom encountered by the general public in the UK [or in the US] (NRBP, 2001: 164).

The group further recognizes that the scientific evidence suggesting that exposure to power-frequency electromagnetic fields poses an increased risk of cancer is very weak. Virtually all of the cellular, animal and human laboratory evidence provides no support for an increased risk of cancer incidence following such exposure to power frequencies, although sporadic positive findings have been reported. In addition, the epidemiological evidence is, at best, weak.

These conclusions of the Advisory Group are consistent with previous reviews by the NIEHS (1999) and the Health Council of the Netherlands (HCN, 2000). The NRPB response to the Advisory Group report states "the review of experimental studies by [the Advisory Group] AGNIR gives no clear support for a causal relationship between exposure to ELF-EMFs and cancer" (NRPB, 2001:1).

2.4.2 Health Council of the Netherlands

The Health Council of the Netherlands has prepared an update of its 1992 Advisory Report on exposure to electromagnetic fields (0 Hz to 10 MHz) (HCN, 2000). Eight members of the Expert Committee prepared the report. The Expert Committee based its analysis on the review and summaries of the studies provided in the NIEHS (1998) and concurred with the views of the director of the NIEHS (1999). For the update, the Committee evaluated a number of publications that appeared after these reports, e.g., McBride (1999) and Green et al. (1999a), and wrote:

> The committee thinks that the quality of the relevant epidemiological research has improved considerably since the publication of the advisory report in 1992. Even so, this research has not resulted in unequivocal, scientifically reliable conclusions (p. 15).

The Council emphasizes that the associations with EMF reported in epidemiologic studies are strictly statistical and do not demonstrate a cause-and-effect relationship. In their view, experimental research does not demonstrate a causal link or a mechanism to explain EMF as a cause of disease in humans. They concluded that there is no reason to recommend measures to limit residence near overhead power lines (HCN, 2000).

2.4.3 Institution of Electrical Engineers (IEE) of Great Britain

One of the recent reviews was that of the Institution of Electrical Engineers (IEE) of Great Britain (IEE, 2000). In 1992, the IEE set up a Working Party whose eight members review the relevant scientific literature and prepare reports of their views. Their conclusion is based on recent major epidemiologic studies and the scientific literature built up over the past 20 years. In May 2000, the Working Party concluded " . . . that there is still not convincing scientific evidence showing harmful effects of low level electromagnetic fields on humans" (IEE, 2000:1).

3.0 Ecological Research

Scientists have studied the effects of high-voltage transmission lines on many plant and animal species in the natural environment. In this section, we briefly review the research on the effects of EMF on ecological systems to assess the likelihood of adverse impacts. In addition to the comprehensive review of research on this topic by wildlife biologists at the BPA (Lee et al., 1996), we searched the published scientific literature for more recent studies published between 1995 and February 2001.

3.1 Fauna

The habitat on the transmission right-of-way and surrounding area shields most wildlife from electric fields. Vegetation in the form of grasses, shrubs, and small trees largely shields small ground-dwelling species such as mice, rabbits, foxes and snakes from electric fields. Species that live underground, such as moles, woodchucks, and worms, are further shielded from electric fields by the soil. Hence, large species such as deer and domestic livestock (e.g., sheep and cattle) have greater potential exposures to electric fields since they can stand taller than surrounding vegetation. However, the duration of exposure for deer and other large animals is likely to be limited to foraging bouts or the time it takes them to cross under the line. Furthermore, all species would be exposed to higher magnetic fields under a transmission-line than elsewhere, as the vegetation and soil do not provide shielding from this aspect of the transmission-line electrical environment.

Field studies have been performed in which the behavior of large mammals in the vicinity of high-voltage transmission lines was monitored. No effects of electric or magnetic fields were evident in two studies from the northern United States on big game species, such as deer and elk, exposed to a 500-kV transmission line (Goodwin 1975; Picton et al., 1985). In such studies, a possible confounding factor is audible noise. Audible noise associated with high-voltage power transmission lines (with voltages greater than 110-kV) is due to corona. Audible noise generated by transmission lines reaches its highest levels in inclement weather (rain or snow).

Much larger populations of animals that might spend time near a transmission line are livestock that graze under or near transmission lines. To provide a more sensitive and reliable test for adverse effects than informal observation, scientists have studied animals continuously exposed to fields from the lines in relatively controlled conditions. For example, grazing animals such as cows and sheep have been exposed to high-voltage transmission lines and their reproductive performance examined (Lee et al., 1996). In some studies, the effects of exposure over one or more successive breedings were examined (Angell et al., 1990). Compared to unexposed animals in a similar environment, it was found that the exposure did not affect reproductive functions or pregnancy of cows (Algers and Hennichs, 1985; Algers and Hultgren, 1987).

A group of investigators from Oregon State University, Portland State University, and other academic centers evaluated the effects of long-term exposure to EMF from a 500-kV transmission line operated by BPA on various cellular aspects of immune response, including the production of proteins by leukocytes (IL-1 and IL-2) of sheep. In previous unpublished reports, the researchers found differences in IL-1 activity between exposed and control groups. However, in their most recent replication, the authors found no evidence of differences in these measures of immune function. The sheep were exposed to 27 months of continuous exposure to EMF, a period of exposure much greater than the short, intermittent exposures of sheep grazing under transmission lines. Mean exposures of magnetic and electric fields were 3.5-3.8 µT (35-38 mG) and 5.2-5.8 kV/m, respectively (Hefeneider et al., 2001).

Scientists from Illinois Institute of Technology (IIT) monitored the possible effects of electric and magnetic fields on fauna and flora in Michigan and Wisconsin from 1969 – 1997 to evaluate the effects of an above-ground, military communications antenna operating at 76 Hz. The antenna produces EMF similar in physical characteristics to those produced by high-voltage transmission lines but of much lower intensity. This study included embryonic development, fertility, postnatal growth, maturation, aerobic metabolism, and homing behavior, and showed no adverse impacts of ELF electric and magnetic fields on the animals (NRC, 1997).

The hormone melatonin, secreted at night by the pineal gland, plays a role in animals that are seasonal breeders. Studies in laboratory mice and rats have suggested that exposure to electric and/or magnetic fields might affect levels of the hormone melatonin, but results have not been consistent (Wilson et al., 1981; Holmberg, 1995; Kroeker et al., 1996; Vollrath et al., 1997; Huuskonen et al., 2001). However, when researchers examined sheep and cattle exposed to EMF from transmission lines exceeding 500-kV, they found no effect on the levels of the hormone melatonin in blood, weight gain, onset of puberty, or behavior in sheep and cattle (Stormshak et al., 1992; Lee et al., 1993; Lee et al., 1995; Burchard et al., 1998).

Another part of the IIT study examined the effect of the antenna system fields on the growth, development, and homing behavior of birds. Studies of embryonic development (Beaver et al., 1993), fertility, postnatal growth, maturation, aerobic metabolism, and homing behavior showed no adverse impacts of ELF electric and magnetic fields on the animals (NRC, 1997). Fernie and colleagues studied the effects of continuous EMF exposure of raptors to an electric field of 10 kV/m in a controlled, laboratory setting. The exposure was designed to mimic exposure to a 765-kV transmission line.

Continuous EMF exposure was found to reduce hatching success, yet increase egg size, fledging success, and embryonic development (Fernie et al., 2000). In a study of the effects on body mass and food intake of reproducing falcons, the authors found that EMF lengthened the photoperiod as a result of altered melatonin levels in the male species, yet concluded that "EMF effects on adult birds may only occur after continuous, extended exposure" (p. 620), which is not likely to occur from resting on power lines (Fernie and Bird, 1999).

Several avian species are reported to use the earth's magnetic field as one of the cues for navigation. It has been proposed that deposits of magnetite in specialized cells in the head are the mechanism by which the birds can detect variations in the inclination and intensity of a dc magnetic field (Kirschvink and Gould, 1981; Walcott et al., 1988). In early studies of transmission lines, it was reported that the migratory patterns of birds appeared to be altered near transmission lines (Southern, 1975; Larkin and Sutherland, 1977). However, these studies were of crude design, and Lee et al. (1996) concluded that, "During migration, birds must routinely fly over probably hundreds (or thousands) of electrical transmission and distribution lines. We are not aware of any evidence to suggest that such lines are disrupting migratory flights" (p. 4-59). No further studies on this topic were identified in the literature.

Bees, like birds, are able to detect the earth's dc magnetic fields. They are known to use magnetite particles, which are contained in an abdominal organ, as a compass (Kirschvink and Gould, 1981). In the laboratory, they are able to discriminate between a localized magnetic anomaly and a uniform background dc magnetic field (Walker et al., 1982; Kirschvink et al., 1992).

Greenberg et al. (1981) studied honeybee colonies placed near 765-kV transmission lines. They found that hives exposed to electric fields of 7 kV/m had decreased hive weight, abnormal amounts of propolis (a resinous material) at hive entrances, increased mortality and irritability, loss of the queen in some hives, and a decrease in the hive's overall survival compared to hives that were not exposed. Exposure to electric fields of 7-12 kV/m may induce a current or heat the interior of the hive; however, placing the hive farther from the line, shielding the hive, or using hives without metallic parts eliminates this problem. ITT studied the effects of EMF on bees exposed to the 76-Hz antenna system at lower intensities and concluded that these behavioral effects of "ELF-EMF impacts are absent or at most minimal" (NRC, 1997:102).

Reptiles and amphibians contribute to the overall functioning of the forest ecosystems. However, little research has been performed on the effects of EMF on reptiles and amphibians in their natural habitat.

3.2 Flora

Numerous studies have been carried out to assess the effect of exposure of plants to transmission-line electric and magnetic fields. These studies have involved both forest species and agriculture crops. Researchers have found no adverse effects on plant responses, including seed germination, seedling emergence, seedling growth, leaf area per plant, flowering, seed production, germination of the seeds, longevity, and biomass production (Lee et al., 1996).

The only confirmed adverse effect of transmission lines on plants was reported for transmission lines with voltages above 1200-kV. For example, Douglas Fir trees planted within 15 m of the conductors were shorter than trees planted away from the line. Shorter trees are believed to result from corona-induced damage to the branch tips. Trees between 15 and 30 m away from the line suffered needle burns, but those 30 m and beyond were not affected (Rogers et al., 1984). These effects would not occur at the lower field intensities expected beyond the right-of-way of the proposed 500-kV transmission line.

3.3 Summary

The habitat on the transmission-line rights-of-way and surrounding areas shield smaller animals from electric fields produced by high-voltage transmission lines; thus, vegetation easily shields small animals from electric fields. The greatest potential for larger animals to be exposed to EMF occurs when they are passing beneath the lines. Studies of animal reproductive performance, behavior, melatonin production, immune function, and navigation have found minimal or no effects of EMF. Past studies have found little effect of EMF on plants; no recent studies of plants growing near transmission lines have been performed. In summary, the literature published to date has shown little evidence of adverse effects of EMF from high-voltage transmission lines on wildlife and plants. At the field intensities associated with the proposed 500-kV, no adverse effects on wildlife or plants are expected.

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